ON THE INFLUENCE OF SOLAR ACTIVITY ON THE INTENSITY OF COSMIC RAYS

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Plate XXVI

ABSTRACT. A report of a sudden increase in cosmic ray intensity following the solar flare on January 25, 1949 is given. It is accompanied by a rapid diminution in cosmic ray intensity and a slow recovery as a result of the concomitant magnetic storm. The relationship of the two processes with solar activity is discussed.

INTRODUCTION

The intensity of cosmic radiation at any place on the surface of the earth is subject to variations, which are, more or less, world-wide in character. These variations are of two kinds: periodic and non-periodic. The former type mainly consists of:

(*a*) The diurnal variation depending on solar time
(*b*) The diurnal variation depending on siderial time
(*c*) The seasonal variation and
(*d*) The 27-days period variation.

Most of these periodic variations have been accounted for, on theoretical grounds by Vallarta and Godart (1939), as being due to the relative change in the position and orientation of the magnetic dipoles of the Sun and the earth during their respective career.

Amongst the non-periodic variations the most important ones are

(*e*) magnetic storm effect as observed by Forbush (1937) and Hess and Demmelmair (1937), and
(*f*) Solar flare effect as reported by Forbush (1946), Duperier (1945), Dolbear and Elliott (1947) and Neher and Roesch (1948).

Both these non-periodic effects owe their origin to the same source, *viz.*, solar activity due to sunspots. From the observations enumerated above, it may be taken to be definitely established that on the Sun, sometimes active regions appear which are closely associated with sunspots and in which charged particles can be accelerated to energies of the order of $\sim 10^9$ e. v. The mechanism of such a process was first postulated by Swann (1933), who solved in relativistic mechanics, the problem of acquirement of cosmic rays

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energies by charged particles, through the agency of magnetic fields associated with sunspots. A simpler model has been envisaged by Bagge and Biermann (1948) which readily shows that on account of the permanent magnetic field of the Sun, it is not possible for charged particles of energy $\sim 10^9$ e. v. to leave the Sun except in a very narrow band at high latitudes. This difficulty is sometimes surmounted in the following way :

A particle projected during a solar flare will come under the combined action of the Sun and the transient magnetic field of a pair of sunspots moving relative to one another. The latter provides a tunnel through the forbidden region of the permanent field through which charged particles can escape from the lower latitudes of the Sun. The existence of this tunnel depends on the relative strength and the orientations of the permanent and transient dipoles, and on the ratio of their field strengths as a function of the distance. If the charged particles which escape from the Sun are endowed with sufficient energy, they would cut across the barrier of the earth's magnetic field and reach its surface at particular places, causing local increase of cosmic rays intensity as observed in solar flare effects. Failing this, the particels would be deflected by the earth's magnetic field and move in trajectories which are crowded on either side of the magnetic equatorial plane at distances of the order of about three times the earth's diameter. The latter are responsible for the magnetic storm effect. Chapman (1937) has offered an explanation of this effect on the basis of Stormer's hypothesis, that a part of the earth's axial magnetic moment is caused by electronic ring currents as described above. If, during a solar flare, these electric ring currents are increased, the magnetic dipole of the earth is strengthened for regions outside of these ring currents, while inside, near the surface of the earth, the magnetic horizontal force is reduced. The increase of the earth's magnetic field in the outer space produces an increased deflection of the paths of the cosmic rays particles, thus reducing the observed cosmic ray intensity on the earth. As is well known, these trajectories have parabolic longitudinal sections. Thus generally, the charged particles emitted by the Sun, and directed towards the earth, will, if not provided with sufficient energy, return to infinity, following asymptotic paths. This explains why a magnetic storm, and the consequent change of cosmic rays intensity, starts suddenly with the initial phase of the storm, followed by a very slow recovery, extending over more than a week during the last phase of the storm. Under very special combination of circumstances more energetic particles are emitted from the Sun which can penetrate the earth's magnetic field and produce local increase in cosmic ray intensity. This, when it happens, precedes the former.

The possibility of charged particles endowed with cosmic rays energies being emitted from the Sun, has revived speculation regarding the origin of cosmic rays. Teller (1948) has advocated that cosmic rays are of solar origin and are kept relatively in the neighbourhood of the Sun by the action of solar magnetic fields. This view has been amplified by Alfvén, Richtmyer and Teller (1949) who argue that the great total energy present in cosmic rays would require very efficient methods for the production of these rays if it be assumed that cosmic rays are spread uniformly throughout inter-galatic space. This difficulty can be somewhat side-tracked by assuming that the cosmic rays are generated on or in the neighbourhood of the Sun and are kept near the solar system by extended magnetic fields. According to this picture, cosmic rays circulate in the neighbourhood of the planetory system for thousands of years, during which time the radiation becomes isotropic. The validity of this solar theory can perhaps be tested by an analysis of a large number of data concerning magnetic storm and solar flare effects.

Since the magnetic storms and allied phenomena are closely associated with solar activity, their intensities and frequencies of occurrence wax and wane over the eleven year solar cycle. The present year, 1949, being situated at the crest of the eleven year-cycle, corresponding with maximum solar activity, it was considered desirable to undertake continuous cosmic rays intensity measurements throughout the year. The present paper, which is first of the series, describes some interesting results of measurements extending over one week following January 25th, 1949.

EXPERIMENTAL

For continuous measurement of cosmic rays intensity, especially extending over long periods of time, the pressure ionisation chamber is still perhaps the best available instrument. Standard ionisation chambers have been designed and described by Kolhröster (1926), Hoffmann and Lindholm (1928) Steinke (1928), Millikan and Cameron (1931) and Compton, Wollan and Bennett (1934). Our ionisation chamber assembly consists essentially of five parts. These are briefly described below :

(1) The collecting volume or ionisation chamber proper is a steel cylinder of 3 mm wall thickness with two hemispherical ends, welded with suitable

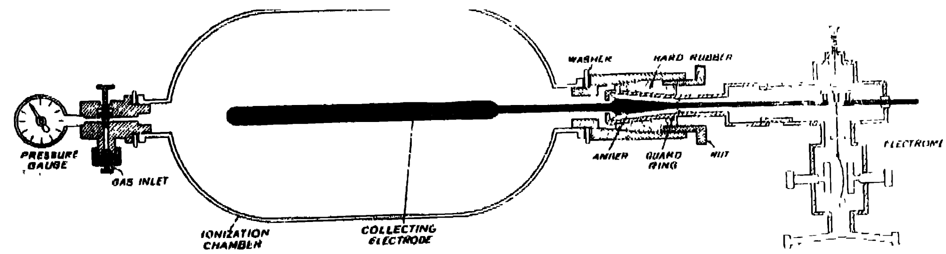


FIG. 1

flanges. One of the flanges is fitted with a gas inlet arrangement furnished with pressure gauge and needle valve while the other supports the highly insulated collecting electrode assembly and guard-ring. The volume of the chamber is five litres and is filled with argon at a pressure of 200 lbs per sq.

in. The vessel contains no network which, according to Steinke and and Schindler (1932) and Pfundt (1933), is unnecessary in high pressure chambers with a comparatively small electric field near the central electrode. In order to further suppress the radioactivity of the walls, the inside has been coated with a mixture of collodion and lamp-black to a thickness of 0.1 mm. This layer absorbs the α-particles. The vessel is insulated from its surroundings by an ebonite support.

(2) The guard-ring consists of a conical brass tube wedged between the hard-rubber and amber plugs. Suitable shields are screwed on both ends of the guard-ring, serving the following important functions :

(*a*) Protection of the collecting electrode from leakage currents which might flow across the insulation.

(*b*) Provision of electrostatic shielding for the electrode system.

(*c*) Elimination of the occurrence of the troublesome phenomena associated with the electrical polarisation of the insulators and their relaxation.

(3) A cylindrical brass rod, of five mm. diameter, and coaxial with the chamber, constitutes the inner collecting electrode. It is supported by being screwed into a small conical brass plug embedded in the insulator amber block. Screwed at the other end of the brass plug is a narrow brass rod, which is connected to the electrometer fibre and is "earthed" every hour by a phosphor-bronze strip operated by a clock-work arrangement.

(4) The measuring instrument is an unifilar electrometer of Wulf's type. The sensitive system consists of a Wollaston filament of 2μ thickness, attached by its lower end to a quartz spring bow. Suitable sensitivity is obtained by adjusting the tension of the filament and also varying the voltage or the position of the knife-edges. Like the apparatus of Hoffmann, Steinke or of Compton, the electrometer is placed outside the ionisation vessel. An extension of the guard-ring enclosing the space between the chamber and the electrometer is made air-tight. This space as well as the electrometer vessel are kept dry by means of phosphorus pentoxide.

(5) The recording apparatus consists of a camera with a cylindrical lens. Cinematographic film is wrapped round a drum mounted on ball-bearing pivots and slowly driven by a clock-work mechanism which is suitably geared to make one complete revolution in twenty-four hours.

The Wollaston filament is illuminated from behind and its image is thrown on the film with the help of a microscope as a dark line against a bright circular background. A sample strip, embodying hourly photographic records of the position of the filament, is shown in Fig. 3, Plate XXVI The slope of each line is a measure of the average cosmic-ray intensity during that hour.

The bottom and the four sides of the chamber are surrounded by lead bricks of 5 cms. thickness in order to cut down the local radiation. When the top is covered with similar lead bricks, measurements are said to have been taken with closed shield. Otherwise, measurements have been taken with open shield.

A potential of +450 volts is obtained from three well insulated dry batteries and is laid directly on the wall of the chamber, so that the entire volume is used for the measured ionisation.

A schematic diagram of the arrangement is shown in Fig. 1, whilst a photograph of the ionisation chamber assembly is given in Fig. 2 of Plate XXVI.

The measurements were carried out in a small room situated on the top of the Bose Research Institute. The ceiling and one of the walls of the room consisted of thin cement asbestos sheets; the other three walls were constructed of slender masonary In order to minimise the temperature fluctuations, the outer walls and the roof were thickly coated with aluminium paint. Subsequently, the room has been thermally insulated by covering the floor with cork slabs while the walls and roof have been reinforced by double layer of tentest with cotton walls sandwiched between them. In order to keep the temperature and humidity of the room at constant controlled values, an air-conditioning unit is being installed.

RESULTS

If all the ions of one sign produced in a chamber of volume V are collected by the central electrode, then the ionization current observed can the written as

$$i = ePI_s V \qquad \dots \quad (1)$$

where e = electron charge = 4.77×10^{-10} e.s.u.

P = pressure of the enclosed gas in atmospheres.

I_s = the number of pairs of ions produced per cc. per sec. per atmosphere

V = volume of the chamber in cc.

The rate of change of potential in volts per second is

$$d\phi/dt = 300\ ePI_s V/c \qquad \dots \quad (2)$$

where c is the capacity of the central electrode system.

In our experimental arrangement,

P = 13.3 atmospheres (200 lbs per sq. inch.)

V = 5000 cc.

c = 20.2 cms.

and $d\phi/dt = 1.8 \times 10^{-3}$ volt per sec., the chamber being surrounded by lead bricks of 5 cms. thickness;

whence I_s is calculated out to be 3.9 ions per cc. per sec.

Now, the total ionization I_s is the sum of the ionizations due to cosmic rays and that due to local radiations.

$$i.e. \qquad I_s = C + L \qquad \dots \quad (3)$$

These two components C and L have been differentiated adopting the method of Compton (1933). Following Compton, our ionisation chamber was shielded with lead bricks of thickness 2.5 cms and 5 cms in succession. Ionisation measurements were made in each of the above set-ups when no Ra source was in the neighbourhood. Next, a 1 mg Ra capsule, enclosed within a lead container, was placed at an approximate distance of one metre from the middle of the chamber and the ionisation measurements repeated. From these data, one can get C and L by the use of the formulas

$$C = [a/(a-b)](R_2 - bR_1)I_\gamma \qquad \dots \quad (4)$$

$$L = R_2 I_\gamma - C \qquad \dots \quad (5)$$

where $a = \dfrac{C_2}{C_1} = \dfrac{\text{ionization due to cosmic rays through 5 cms. lead shield}}{\text{ionization due to cosmic rays through 2.5 cms. lead shield}}$.

$b = \dfrac{L_2}{L_1} = \dfrac{\text{ionization due to local-rays through 5 cms. lead shield}}{\text{ionization due to local-rays through 2.5 cms. lead shield}}$.

$$\text{and} \quad R_2 = \frac{i_2}{(i_r - i_2)} = \frac{i_2}{I_\gamma} \qquad \dots \quad (6)$$

$$R_1 = \frac{i_1}{i_2} \cdot R_2 = \frac{i_1}{I_\gamma} \qquad \dots \quad (7)$$

i_1 = ionization current through 2.5 cms. lead shield, radium absent.

i_2 = ionization current through 5 cms. lead shield, radium absent.

i_r = ionization current through 5 cms. lead shield, radium at 1 meter.

I_γ = ionization current through 5 cms. lead shield, due to local γ-rays alone.

From the above equations, we find

$C = C_2 = 2.4$ ions per c.c. per sec.

$L = L_2 = 1.4$ ions per c.c. per sec.

It may be mentioned, however, that the magnetic storm measurements described hereafter, were undertaken with the open shield, *i.e.*, with the top surface of ionization chamber uncovered.

Since cosmic ray intensity varies with change of barometric pressure, a correction for atmospheric pressure variation was necessary. Assuming that the ionization pressure relationship is linear, (Wollan, 1939) that there is a change of 2% in ionization per cm. change of pressure and that the barometric pressure coefficient is negative, all our data have been corrected for a constant barometric pressure of 1013 millibars.

Moreover, the temperature variation of the room in which the apparatus was housed, affected the sensitivity of the unifilar electrometer. This necessitated the determination of temperature coefficient of the instrument.

To do this the rate of change of sensitivity of the electrometer with temperature had to be determined. This was done by checking the deflection of the electrometer fibre for a constant voltage at different times of day and night in order to have sensitivity records at different temperatures. From the values of sensitivity thus obtained at different temperatures, the temperature coefficient of the instrument was calculated graphically and all the data were corrected for a mean temperature. The cosmic ray intensity measurements were first started in December, 1948, when a comet was visible. No appreciable change in intensity during the period of appearance of the comet could be detected.

Unfortunately, however, due to other pre-occupations no records could be taken during the week preceding January 25, 1949. A report of sunspots and radio fade-out appearing in the morning paper of January 25 prompted us to begin the measurements from the afternoon of that date. The result of measurements carried out during the following week is shown graphically in Fig. 4. Each point represents the average cosmic ray intensity at the corresponding hour, corrected for barometric pressure and room temperature. It will be noticed that an unusual increase of cosmic ray intensity, about 22% above the normal value was recorded at the very commencement of our measurements. This value rapidly diminished till it was about normal by the mid-day of the 26th and then climbed down to about 12% below normal when mid-night was reached. The subsequent course of the intensity curve is subnormal and jagged with a gradual upward tendency to attain the normal value which it did after twelve days.

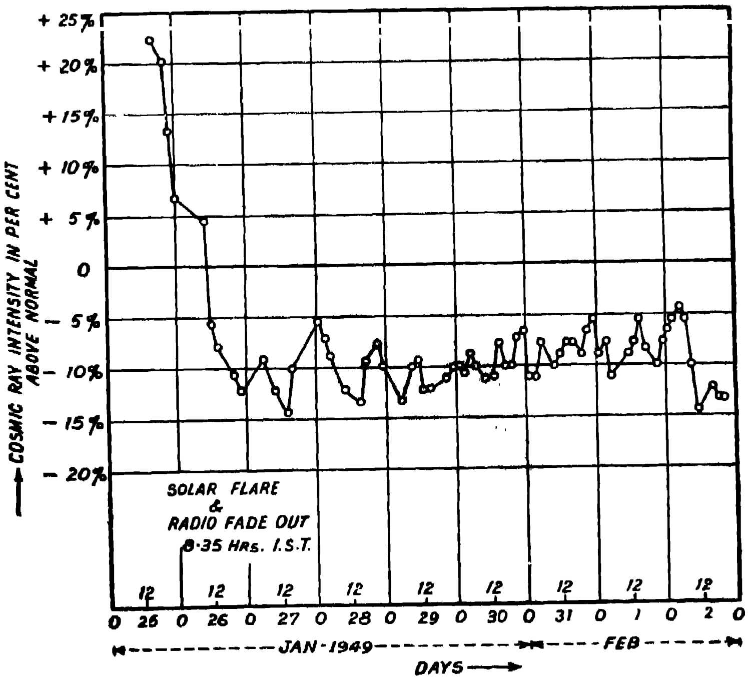


FIG. 4

Table I shows the list of solar flares observed at Kodaikanal during the month of January, 1949, whilst Table II gives the data of magnetic variations observed.

TABLE I

Month and date	Solar flares		Mean Lat.	Mean Longitude
	Time (I. S. T.)	Intensity		
January, 1949				
21st	8.15–8.40	slight	23° N	24° E
23rd	8.00–9.31	great	20° N (a)	5° W
			22° N (b)	5° E
25th	8.35–8.46	moderate	25° N	16° W

In addition to the above flares, observations showed disturbed or active regions around sunspot groups on the following days, *viz.*, February 1, 2, 3 etc.

TABLE II

Date	International character figure	Magnetic activity
January, 1949		
21st	0	Quiet
22nd	1	Slightly disturbed
23rd	1	Slightly disturbed; crochet at 13.29 hrs.
24th	1	Slightly disturbed; sudden commencement of severe storm at 23.58 hrs.
25th	2	Greatly disturbed; strom continued
26th	2	Greatly disturbed; storm continued till 18.28 hrs.
27th	1	Slightly disturbed
28th	0	Quiet

DISCUSSION OF THE RESULT

It is to be admitted that the result obtained by us, as outlined above is rather surprising. Forbush (1946) observed unusual increase in cosmic ray intensity, associated with solar flares at Cheltenham (geomagnetic latitude 50°N), Godhavn (78°N) and Christchurch (48°S), but not at Huancayo (1°S). It is, therefore, somewhat unusual that similar increase in cosmic ray intensity should have been observed at a place having low geomagnetic latitude as Calcutta (12°N). Moreover, it transpired, on enquiry, that no

Fig. 2

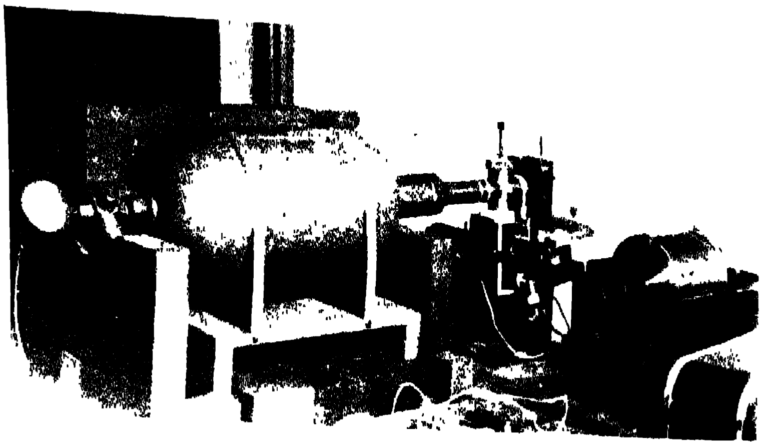
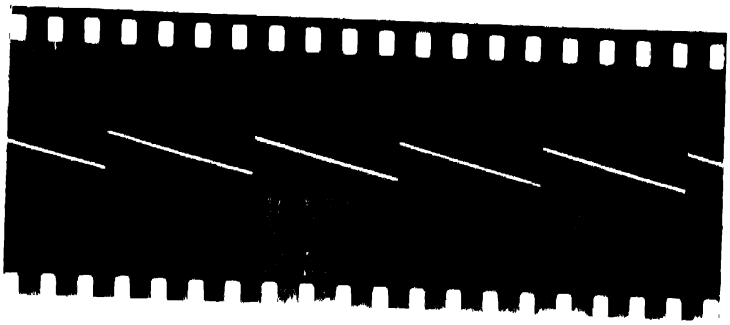


Fig. 3



such increase was recorded this time at Washington or Manchester.* It is difficult to conceive why the observation of an increase in cosmic ray intensity due to a solar flare at a lower geomagnetic latitude should not be substantiated at a higher latitude. It might perhaps be mentioned in this connection that Sarna and Sharma (1946) got an abnormal increase in cosmic ray intensity at Lahore (21°N) on August 3, 1946, which was not corroborated by the record of Dolbear and Elliott (1947) at Manchester.† Such examples are, however, by no means rare. For example, the large increase in cosmic ray intensity observed by Forbush on February 28, 1942 at Cheltenham, and Godhavn as reported earlier, was not recorded by Duperier (1945), in London (70°N). On the other hand, the small increase observed by Forbush a few days later on March 7, 1942 at both the above places, was readily corroborated by Duperier. All these facts lend support to the hypothesis that the charged particles arrive at the earth only along certain directions after travelling through the magnetic field of the Sun, the earth and the transient sunspot field. Further, according to Forbush, Gill and Vallarta (1949), during solar flares accompanied by an increase of cosmic radiation, one would expect important departures from isotropy as observed at the earth. Such departures would occur only at certain points on the earth and only in certain directions. In a private communication, commenting on our results, Prof. Vallarta has remarked :

"It would not be a priori impossible for cosmic rays emitted from the Sun during a flare to reach the latitude of Calcutta, nor would it be ruled out that such rays would be observed there and not elsewhere, for instance in Cheltenham. The least latitude of arrival depends on the relative location of the tunnel and the earth." Prof. Vallarta has also kindly promised to get the relevant sunspot data from Mount Wilson and calculate whether the rays had required energy to reach the geomagnetic latitude of Calcutta. Even

* We are thankful to Dr. P. S. Gill and Dr. R. L. Sen Gupta for this information.

† The large increase of cosmic-ray intensity recorded on July 25, 1946 by Forbush, Dolbear and Elliott, and Neher and Roesch, has been associated with the intense solar flare observed on that date. None of the above observers could, however, detect a second increase on the following August 3, 1946, as reported by Sarna and Sharma. It occurred to us, that there might have been two successive active solar flares on these dates like those on February 28 and March 7, 1942 respectively. On looking through the data, kindly supplied by the Director of Solar Physics Observatory, Kodaikanal, on solar flares recorded during that period in different places, it has come to our notice that an intense solar flare had actually been observed at Ondrejov (Prague) on August 3, 1946. The close simultaneity of the time of occurrence of the solar flare and the observation of increased intensity of cosmic rays by Sarna and Sharma leads us to believe that the two phenomena were perhaps interdependent. The relevant solar flare data are given below :

Observatory	Date 1946	Times (G. M. T.)		Co-ordination of Eruption		Importance
		Begin	End	Latitude	Longitude	
Ondrejov (Prague)	August 3	13. 11	13. 54	26 S	13 W	3

then, he says, it would not be possible for him to locate their exact place of arrival at the earth until the integrations of equations of motion was finished, which he hoped to do in near future.

It will be noticed that the increase of cosmic ray intensity was recorded at Calcutta on January 25, 1949, when, as shown in Table II, a severe magnetic storm was raging. This is, however, not very unusual. Corlin (1931) found that in 30 out of 32 cases there was an increase of ionisation after the beginning of the storm on an average 4.5% of the mean ionizations. It may also be mentioned that the increase in cosmic ray intensity observed on March 7, 1942 by Forbush and also by Duperier, occurred when the world had not fully recovered from the effect of the previous magnetic storm.

It is therefore likely that the aperture of the tunnel opened after the moderate solar flare of the January 25, when the world was passing through a magnetic storm in the wake of the great solar flare of January 23, 1949.

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